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ECONOMIC ASPECTS OF SPECTRUM MANAGEMENT

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Abstract

This paper addresses problems associated with the allocation of a scarce resource--the radio frequency spectrum. It is observed that the current method of allocation very likely does not allocate the resource to those most valuing its use. Because users of the spectrum are not required to pay the "opportunity cost" of their spectrum use (defined as the benefits foregone by not employing the resource in its best alternative use) they are, in effect, being subsidized. Furthermore, there is little or no incentive for them to improve and conserve their use of the resource. If anything, incentives run counter to this goal.

A number of schemes to encourage more economically efficient use of the resource have been proposed. These range from institution of a free market in radio frequency rights to implementation of federally administered usage fees. The first part of the paper sets out economic criteria by which the effectiveness of resource allocation schemes can be judged, and offers some thoughts on traditional objections to implementation of market characteristics into frequency allocation.

The second part of the paper discusses the problem of dividing orbit and spectrum between two satellite services sharing the same band, but having significantly different system characteristics. The problem is compounded by the likelihood that one service will commence operation much sooner than the other. Some alternative schemes are offered that, within proper international constraints, could achieve a desired flexibility in the division of orbit and frequency between the two services domestically over the next several years.

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I. WELFARE ECONOMICS AND SPECTRUM MANAGEMENT

a. Introduction

Much has been written in recent years about how the Federal Communications Commission (FCC) and the Interdepartmental Radio Advisory Committee (IRAC) allocate a scarce resource - the radio frequency spectrum. The interest in this subject stems from the fact that radio spectrum [1] is allocated in a manner so radically different from that for most other resources in our economy. From the standpoint of economic efficiency, this method of allocation is considered by many to be highly questionable.

The present method of radio spectrum allocation [2] has its roots in the Radio Act of 1927 (Public Law 69-632), the purpose of which was stated in the preamble as follows [3].

"... this Act is intended to regulate all forms of interstate and foreign radio transmissions and communications within the United States, its territories and possessions; to maintain the control of the United States over all the channels of interstate and foreign radio transmission; and to provide for the use of such channels, but not the ownership thereof, by individuals, firms, or corporations, for limited periods of time, under licenses granted by Federal authority, and no such license shall be construed to create any right, beyond the terms, conditions, and periods of the license."

Most of the provisions of this act were later incorporated into the Communications Act of 1934 (P.L. 73-416), the basis of the FCC's current authority. In effect, the federal government nationalized the radio spectrum, apparently out of the fear that continued unregulated use would result in levels of radio interference rendering the resource entirely useless [4].

As "trustee" of the resource, the federal government is charged with the following significant responsibilities:

Sec. 1, ". . . to make available, so far as possible, to all people of the United States a rapid, efficient, nation-wide and world-wide wire and radio communication service with adequate facilities at reasonable charges"

Sec. 303(c), "Assign bands of frequencies to the various classes of stations, and assign frequencies for each individual station and determine the power which each station shall use and the time during which it may operate"

Sec. 303(f), "Make such regulations not inconsistent with law as it may deem necessary to prevent interference between stations and to carry out the provisions of this Act: Provided, however, that changes in the frequencies, authorized power, or in the times of operation of any station, shall not be made without the consent of the station licensee unless, after a public hearing, the Commission shall determine that such changes will promote public convenience or interest or will serve public necessity, or the provisions of this Act will be more fully complied with"

Sec. 303(g), "Study new uses for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest"

These provisions underlie the present "modus operandi" of the Federal Communications Commission. As it is now, the FCC must decide how, and by whom, radio frequencies will be used [5].

Aside from the issue of the political implications of centralized control of an information medium (certainly not to be ignored in this case), the FCC faces the problem that plagues any central allocatory authority: insufficient genuine information to make intelligent judgments on how to distribute the resource under its purview. This is not to say that applicants and licensees are not eager to supply plenty of information, but it is information inevitably colored to reflect the vested interest of its supplier [6]. Sorting the

genuinely relevant information out of reams of data is an unenviable task often far beyond the capability of an agency with the FCC's resources.

One place market allocation appears to be generally superior to administrative control is in the economy of information required to guide resources to their highest valued use [7]. No single entity needs to know who has the greatest need or who will make best use of a resource. All relevant information about the marginal value of a resource to those actively competing for its use is contained in one number--the market price. In aggregate, the amount of information in the economy can remain immense, but the decentralization of decision-making eliminates the transaction cost associated with transferring large amounts of information to a centralized authority, and tends to ensure that decisions are based only on relevant information [8].

Owen set out three serious flaws in present methods of radio frequency allocation and assignment as follows [9]:

- 1) There is no formal mechanism for trading spectrum rights among users;
- 2) no price is paid for use of the resource;
- 3) the criteria by which users are chosen are vague and, from the standpoint of both quality and economic efficiency, often counter-productive.

Both the first and second flaws have significant impacts upon innovation and the development of new services that often follow it. Spokesmen for the development of new communications services often find themselves in conflict with the FCC over whether or not frequencies

will be allocated to potential new, but as yet non-existent, services. They correctly perceive that failure to secure frequency allocations now for future services may preclude those services from coming into being. Without some assurance that these allocations can be obtained, people hesitate to invest in development and construction of equipment that would be rendered useless by shortages of usable frequencies.

One cause of this dilemma is the effective nontransferability of either present or future radiation rights [10]. Under the present system, there is often no incentive for old users to yield to new, even when the new user would be willing to pay the older user much more than the value that the old user would assign to his unit of spectrum. If old users perceived spectrum use as having a price, either because they paid a fee, or because they could have all or part of their radiation rights bought out by new users, then there would indeed be an incentive for old services to yield use of the spectrum to more valuable new services. In such a world, providers of new services would know that, when the time came, they would be able to obtain frequencies. The only uncertainty would be over what the price would be (even this uncertainty could be reduced by an appropriate futures contract with a present user). From the standpoint of risk, this would be preferable to the current system, where the new service has no assurance that spectrum with the desired characteristics can be obtained in the desired amounts, regardless of its willingness to pay the price.

Certain implications of nontransferability of any rights can be gleaned from the following proposition, derived from welfare economics:

If any number of parties enter into a transaction of their own volition, and if the transaction has only nonnegative impacts on nonparticipating parties, then social welfare is unambiguously increased by the transaction.

If there is a nonparticipating party on which there is an adverse (negative) impact, it may still be possible to expand the definition of the transaction to include compensation to this party and satisfy the above criterion. If parts of such expanded transactions are allowed to be only potential (that is, transactions that could take place but won't necessarily) then the above becomes the familiar "Kaldor Criterion" [11].

If transactions of the type above are blocked, as present communications law dictates that they are, then society has foregone an increase in its welfare. This is the primary reason for the economist's interest in the shortcomings of current radio frequency allocation methods.

In a world of perfect markets, all transactions would be of the type described above (to be perfect, impacts upon nonparticipants should be strictly zero). Furthermore, when certain familiar assumptions are made about the preferences of the participants in this market (nonsaturation, etc.) and transactions costs (they are zero or sufficiently negligible) then the resources allocated by the market will be allocated in an economically efficient manner. This

economically efficient allocation of resources is a necessary, but not sufficient, condition for maximization of social welfare (however, within reason, it may be defined. Arriving at this definition is the essence of the political problem.).

The stated proposition can be applied even when markets are imperfect, though greater scrutiny of a transaction's effects upon the welfare of third parties is generally required. The presence of monopolies may tend to create more equity and externality problems, but it is still possible, within these constraints, to define certain resource allocations as being "better" or "worse" than others.

Besides inhibiting transfer of rights, "zero price" spectrum use reduces incentive to economize on its use. Thus, spectrum (and orbit too) is always perceived as being in short supply. NASA, for example, sets out the coming saturation of limited spectrum and geostationary orbit resources as the motivation for initiating a research and development program to open the 20/30 GHz band to use by communications satellites. Technologies that make use of the resource more extensive (for example, higher power traveling wave tubes making higher frequencies usable) and more intensive (multi-beam antennas, digital compression, etc.) are seen as a way to increase the resource supply, and thus close the gap between supply and demand. Others, however, have noted a tendency of technology based efforts to increase supply to also increase demand, by making new services possible [12]. Thus, the technologist becomes much like the dog chasing its tail--running faster and faster but never quite catching up.

This perceived shortage is a consequence of the fact that no price is paid for use of the resource. In a properly functioning market, no shortage would exist. In such a world, NASA would see its objective not as closing the gap between supply and demand, but as lowering the resource cost to the user (or, alternatively, expanding the number of services that can be offered on a profitable basis). Also, there would be greater incentive for private sector users to develop ways to use the resource more intensively, since this would directly benefit them financially. NASA's emphasis would probably shift towards (higher risk) extensive development.

Finally, conventional cost-benefit analysis will tend to misestimate the return on communications R&D. Many of the "benefits" measured by such analyses are, in part, measures of the cost of misallocating a resource. Many of the services now excluded (or limited) by the present spectrum allocation and assignment process may have greater value than some of those included (a frequently cited example of what appears to be such a case is land mobile radio vs. UHF television frequency allocations). Likewise, costs associated with some high value services now operating will be overestimated due to their being required to use a suboptimal mix of inputs. If the resource were allocated in a manner that was "economically efficient," then one could be sure that it was only marginal services whose costs and benefits were being compared, and that all cost estimates were being based on optimal input mixes. As it is now, most studies of this sort are largely "stabs in the dark."

b. Economically Efficient Spectrum Use

The word "efficiency" is generally used in several different contexts, often leading to confusion. For example, some engineers characterize efficient spectrum use as accomplishment of a given task by use of technology that minimizes required bandwidth, power, and area of unwanted spillover. Under this definition, efficient use of the resource is identified with minimum possible use, even though such minimal use would require state-of-the-art (expensive) technology across the board.

Another (and I would argue more reasonable) approach to judging efficiency of spectrum use invokes economic efficiency as the chief criterion. Economic efficiency is characterized by optimum use of all resources required for production of a given output. Here, "optimum" means minimization of the total opportunity cost of all inputs used to produce a given output. Opportunity cost is defined as the value of benefits foregone by not employing a given input (i.e., spectrum) in its best alternative use. As an aside, it can be noted that, in a perfect market economy, aggregate opportunity cost minimization corresponds to aggregate profit maximization [13]. If the total opportunity cost of all inputs used in a production process exceeds the value of output, then the activity in question is unprofitable relative to other possible activities; thus, one expects resources to flow to the other (more profitable) activities.

Economic efficiency criteria treat spectrum as just one of many inputs into a given output. Furthermore, inputs can be

substituted for each other. For example, one can use less spectrum by using more sophisticated technology, and vice versa. In deciding how much of each to use, the producer (here a common carrier or broadcaster) compares the relative cost of each, and then alters the mix of inputs so as to minimize total cost.

Under the present allocation methods, the cost of spectrum use to the user (zero, assuming one can get the assignment) does not reflect the opportunity cost (which is greater than zero, since use of a given frequency necessarily excludes certain other potentially worthwhile uses of the same frequency in the same area). The result of this is that common carriers, broadcasters and other users of the spectrum are motivated to substitute greater spectrum use, which they perceive as cost-free, for use of more expensive technologies that reduce or eliminate spectrum use. At the same time, potential spectrum users who cannot get an assignment from the Federal Communications Commission (FCC) are forced to substitute alternative resources in the production of the goods or services they wish to provide, or forego production altogether. Under the FCC's current allocation and assignment scheme, there is nothing to ensure that spectrum is allocated among potential users in such a way as to maximize its contribution to society's aggregate economic product, and good reason to believe that it is not.

The solution to this problem is not, as is often proposed, to accommodate all possible users of the spectrum by use of technology sophisticated enough to allow everyone who wishes to use the spectrum to do so. This kind of approach seeks to reduce the opportunity cost

of spectrum use to zero by substitution of other resources (such as more sophisticated equipment), but fails to recognize that this requires an increase in the opportunity cost of the other resources used in the production of a specified level of output. The total opportunity cost of all inputs is unlikely to be minimized by such an approach.

The best (in the sense of economically efficient) solution to the spectrum allocation problem can only be achieved if the cost of spectrum use to the user can be made to reflect its opportunity cost. If this could be achieved, competitive economic forces would then tend to push spectrum assignments into the hands of those groups or individuals making the most economically productive use of the resource.

If the cost of the spectrum use truly reflected opportunity cost, spectrum use by new industries (such as a Land Mobile or Broadcast Satellite Service) that proved to be more profitable than existing uses would drive up the cost of spectrum use to the point where the existing users would be forced to reduce or eliminate their use. Thus, new communications services would not face uncertainty about whether or not spectrum assignments could be acquired that might otherwise stifle their growth.

There are a number of ways in which the cost of spectrum use could conceivably be made to reflect opportunity cost. Among these are institution of a free market for spectrum where assignments can be bought and sold, institution of a spectrum use fee by a centralized regulatory authority, or some mix of markets and regulation. The

market's approach alleged drawback resides in the difficulty of defining and enforcing spectrum property rights (although it can be effectively argued that this same problem plagues the current system). The drawback to centralized allocation with usage fees is that an overwhelming amount of information is required in order to accurately calculate fees that reflect opportunity cost (the shadow pricing problem).

Nevertheless, definite improvement in the current FCC allocation and assignment process can very likely be achieved, even though a "best of all possible worlds" solution may be impossible. Allowing parties now holding licenses to openly buy and sell all or part of their frequency assignments would institute market characteristics tending to lead to more efficient spectrum utilization. In spite of the evident merit of applying such market mechanisms to the allocation of spectrum, however, there remain some traditional objections that must be addressed [14].

c. The Property Rights Problem

It is generally agreed that market mechanisms cannot be successfully introduced into spectrum allocation without first arriving at a workable definition of spectrum property rights. It has been argued that transferable rights for a resource as ethereal as the radio spectrum could become very complicated indeed. For example, determination of who is liable for interference experienced by a certain party would not be trivial in the case where the interference is caused by intermodulation (although, again, this is

no different from the current situation). However, it would be premature to conclude, based on this alone, that enforcement costs [15] for transferable spectrum property rights need be prohibitively high.

The relatively low cost of enforcing property rights in more "concrete" resources, such as land, does not result from the definition of these property rights being any simpler than those proposed for spectrum. A small amount of reflection on the nature of land property rights reveals that they are, in fact, a very complicated set of rights, none of which are absolute in nature. For example, landowners may keep trespassers out, but not kill them; grow corn, but not marijuana; make noise, but not so much that their neighbors can never sleep. Zoning laws make these rights even more restrictive. Land property rights are never exclusive in the sense of society abdicating all control over land use.

It is not so much the level of complexity in a right's definition that determines enforcement costs, but certainly what the right entails. If A uses B's land without B's authorization, there is little doubt that a court will find A liable for damages to B. Certainly about what the outcome of an adjudication will be tends to deter events of this kind from occurring. The disputes most likely to end up in court are those associated with fuzzy delineation of a right. For example, the level of noise A is allowed to make on his/her property is generally not well defined. If A's turbine test facility is sufficiently close to neighbor B's recording studio, one expects there is a good chance the two will end up in court. Sufficient

precision in the definition of property rights would go far towards keeping spectrum users out of court.

The other component significantly affecting enforcement cost is the cost of detection. In the land rights example, it was reasonable to assume that B would detect A's violation of B's property right with high probability at very little cost. However, if the probability of detecting A's violation (and identifying A as the offender) is sufficiently low, and the penalty incurred by A upon being detected is sufficiently low, one might expect A to violate B's right even when it is certain that A would lose to B in an adjudication.

This last problem can be formally illustrated in the following manner:

- a = state of the world in which A's violation goes undetected;
- b = state of the world in which no violation takes place;
- c = state of the world in which A is caught and punished;
- p = the probability A assesses of being caught;
- $u(x)$ = utility of state of the world x.

Making the assumption that $U(a) > U(b) > U(c)$, construct the function $(1-p)U(a) + pU(c)$. This is A's expected utility of violating B's right, and is a strictly decreasing function of p. Furthermore, there exists a p between 0 and 1 such that $U(b) > (1-p)U(a) + pU(c)$ for all probabilities greater than p. That is, above some minimum probability of detection, A will not wish to violate B's right. If one accepts the notion that the perceived probability of detection tends

to be positively correlated with society's actual expenditure on detection, then one can conclude that an increase in this expenditure will tend to decrease the number of people violating other people's rights. Whether the expenditure that maximizes the net social dividend (defined as the value of the provisions prevented minus the cost of detection) will be within reasonable limits is an as yet unresolved question for spectrum rights.

Also, observe that an increase in the penalty for a violation would decrease $U(c)$ and, therefore, the minimum detection probability above which A would not violate B's rights. Thus, under both the current and market techniques for spectrum allocation, there is some flexibility in that higher penalties can be, to some extent, substituted for detection capability, thereby lowering enforcement costs [16].

DeVany et al. [17] have proposed definition of spectrum property rights in terms of hours of transmission, in and out of band limits on radiated power outside a specified geographical area, and bandwidth. The notion is that property rights defined in these "output" terms would be much easier to transfer in whole or part than rights specified in terms of inputs, such as transmitter power or antenna height. In the case of satellites, system performance requirements are already defined in terms of limits on power-flux-density (PFD) over specified geographical areas. This closely approximates the Time-Area-Spectrum (TAS) property right advocated by DeVany et al., though additional complications are introduced by the possibility of interference on earth to space transmissions, especially when the

power levels of these uplinks differ significantly. These additional complications manifest themselves in the form of the resource called "orbit." Segments of the geostationary arc in space are the counterpart of areas of geographical coverage on earth. Any discussion of satellite systems must account for both.

d. Spectrum Monopoly

Besides enforcement costs, concern has been voiced over the strong possibility that markets in radio frequencies would be largely monopolized by the national broadcasting networks in some bands, and by AT&T in others, in an attempt to squeeze out competition. This tendency could be especially severe in the case of AT&T where regulated rate of return monopoly services could be used to cross-subsidize services offered in competitive markets. In principle, AT&T might attempt to squeeze out competitors by buying up spectrum, thereby raising its price to competitors and reducing the volume of services they are able to offer. The standard response to this concern--that antitrust laws can respond to such efforts in the usual manner--is not entirely satisfactory in a time when many large corporations have already demonstrated the capability to drag such proceedings out for years. It would be far preferable to avoid this situation if at all possible.

On the other hand, there are numerous ways in which the telephone company can cross-subsidize services without resorting to spectrum hoarding at all. Spectrum hoarding would succeed as a

squeeze out technique either by completely excluding competitors from use of the spectrum or by forcing them to charge higher prices, allowing the monopoly to undercut them. Total exclusion would seem to make what is occurring too obvious. Hoarding just enough to drive up the competition's prices to where they can be undercut would seem to be a roundabout way of achieving something that could be more easily achieved without hoarding spectrum (i.e. instead of buying up spectrum to hold idle, why not just directly undercut the competition's price?).

Finally, it is not clear that a spectrum market heavily dominated by a regulated monopoly would be worse than the current situation, nor is it clear that the AT&T monopoly is any more constrained by the current FCC from undesirable market practices than they would be if spectrum were allocated by the market place. There is no reason to believe that monopoly or oligopoly could not be just as effectively regulated within the context of a market system as without. This particular objection is largely beside the point.

e. Equipment Lifetimes

An oft-cited argument for maintaining the status quo is that the rigidity of present spectrum allocation methods is necessary to protect the integrity of investment in long-lived radio equipment. The fallacy of this argument lies in the failure to distinguish between the "technical" and "economic" lifetime of equipment. Technical lifetimes may be very long indeed, but it is the economic lifetime that is relevant in economic decisions. Tax and depreciation policies

in the United States, coupled with the rate of innovation and resulting shifts in demands, tend to make the economic lifetimes of most technologies significantly shorter than their technical lifetimes. Innovation in the computer industry, for example, has been so rapid that most machines are scrapped and replaced long before there is any danger of their wearing out.

Economic decisions always involve the comparison of present and expected future alternatives in the present moment. One does not continue to fly Ford tri-motors simply because the equipment has not worn out if conditions of demand are such that the profitability of flying jet aircraft is greater. In fact, one of the strongest arguments against the rigidity of the present system may be that it stifles innovation in communications by favoring existing users at the expense of innovative new users. Airlines wishing to fly new aircraft have little difficulty obtaining pilots or fuel used by airlines operating older aircraft when conditions of demand warrant it, but anybody wishing to offer a new radio service may have great difficulty obtaining spectrum from existing users, even when the demand for the new service is high.

f. Indirect Prices for Resource Use

A not uncommonly heard objection to pricing spectrum use per se is that users already pay an indirect price through their investment in radio equipment and operating expenses. However, attempting to apply this argument to other analogous situations in the economy reveals its weakness. Cars and gasoline, for example, like radio

equipment and radio spectrum, are both complements and substitutes (i.e., more fuel efficient cars can be substituted for greater gasoline consumption, yet the two are always used together). One would be on very weak ground indeed if one attempted to argue that, because people must buy cars to use gasoline, charging a price of zero for gasoline would not lead to inefficient use of the resource. Based on this premise, one could make a strong case that the government should completely subsidize gasoline use for reasons of equity.

If any conclusion can be reached from the ongoing debate over the viability of spectrum markets, it is that further theorizing is unlikely to resolve the question. The economic case has been made. Just as the theoretical physicist must at some point take predictions to the laboratory before further theoretical progress can be made, so it is that economists, both pro and con, must attempt an "experiment" on the viability of spectrum markets before confidence can be placed in their conclusions. Such an experiment for land mobile radio services has already been proposed by Dunn and Owen [18]. Along these lines some thoughts on how market techniques could be applied to the assignment of orbit-spectrum to satellites are presented in the next section of this paper.

II. MARKET ALLOCATION OF ORBIT-SPECTRUM FOR SATELLITE SERVICES

At the time the first man-made earth-orbiting satellites were launched, few expected or believed possible the explosion in the use

of communication satellites that has occurred. Yet, problems resulting from this rapid growth illustrate the drawbacks in the current method of frequency allocation and assignment. There are few places where the need for administrative flexibility is more apparent than in the allocation and assignment of frequencies to services undergoing rapid technologically induced changes.

From the standpoint of system performance, optimum frequencies for satellites lie between about 1 and 10 gigahertz--the so-called "space window." Because this part of the spectrum was already heavily occupied by the time communication satellites went into service, only one of the three bands currently allocated to communication satellites falls within this region (4/6 gigahertz band). The other two bands (12/14 gigahertz and 20/30 gigahertz) require substantially higher transmission powers to overcome effects of atmospheric attenuation. Of these, the 12/14 gigahertz band is only now coming into use while the technology to make the 20/30 band useable remains in the future. It is highly doubtful that the present approach to frequency allocation has minimized the aggregate cost of providing all services, both space and terrestrial, using frequencies above one gigahertz.

Before proceeding with the discussion of orbit and frequency allocation for satellite services, it is necessary to consider the international context of the orbit-frequency allocation and assigned problem.

The International Telecommunications Union (ITU) allocates frequencies to services on a worldwide basis. This is achieved through

administrative radio conferences in which ITU member nations attempt to arrive at a consensus as to how radio frequencies will be used.

Because its success is based on consensus politics, the ITU must attempt to minimize the international constraints on domestic decisions about frequency use within a particular country. The United States, for one, has traditionally argued for the maximum flexibility in determination of how a nation will use frequencies within its borders. Services offered in one part of the world frequently will not even exist in another part. Consequently, strict worldwide allocation of frequencies would lead to tremendous waste in resource use.

The U.S. is fortunate in the respect that, within its region of the world, only a handful of nations are in potential conflict over use of orbit and spectrum. This contrasts with the European situation where many developed nations are concentrated within a relatively small geographical region. Thus, it was tentatively concluded by a 1974 Rand Corporation report that, except for Canada, the probable demand for satellite systems of other countries in the western hemisphere (ITU Region 2) can be met without special coordination with U.S. systems [19]. In fact, most of the orbital arc best suited for use by South American nations does not coincide with segments best suited for U.S. and Canadian systems.

If this conclusion is indeed true, then reliance on market techniques for domestic satellite orbit-spectrum assignment becomes a much simpler political problem internationally than if domestic and international assignments cannot be decoupled. More is said about this shortly.

While people tend to describe satellite systems in terms of the services they provide, it is often useful to think of them purely in terms of their system characteristics. High-powered satellites, such as those being considered for space broadcasting, offer the possibility of small diameter (less sensitive) earth station antennas, thus allowing for systems employing many relatively cheap earth stations. Systems in the fixed satellite service generally employ relatively few earth stations using large diameter (more sensitive) antennas and low powered satellites. Interference between the two types of systems tends to be more severe than interference between systems of the same type. Two reasons for this are, 1) even though larger antennas have relatively high gains, they also have sidelobes that can be illuminated by interfering satellites and, 2) when the interfering satellite is transmitting a higher power density than the satellite transmitting the desired signal, then illumination of the sidelobe results in relatively more interference noise in the receiver.

Approaches to sharing between services using the two system types described have been studied relatively extensively and are fairly well understood [20]. The unsolved problem lies not in how to share between the two services but in how to determine, on the basis of future utility, how much orbit-spectrum must be received for each. If the future demand and course of technological development for each service could be predicted with certainty, there would be no problem in deciding how much orbit-spectrum to allocate to each service at any given time. The difficulty arises both from the

likelihood that one service--the fixed satellite service, will grow more rapidly within the next few years than the other--the broadcast satellite service, and from uncertainty about what technologies will become available to alleviate sharing problems between the two.

One question one might ask is: Should spectrum be held idle for the future use of a service that might possibly come into existence but is not certain to do so? Holding spectrum idle necessarily excludes its use by currently viable services. The opportunity costs incurred may very well outweigh the discounted future benefits of the service for which the spectrum is being reserved. It is unlikely that a satellite service expected to come into existence many years down the road could be justified if this were to require that a significant amount of usable spectrum be held idle for this entire period.

At least one person, Dr. Charles Jackson, has proposed a-worldwide orbit-spectrum market for satellites [21]. Under the Jackson proposal, orbit-spectrum rights are preallotted to each ITU nation. Nations may then lease their rights (which specify a band of frequencies and a certain number of degrees of the geostationary arc locationally unspecified) to the highest bidder through a market run by an international body (the IFRB). The rent from the lease of an orbit-spectrum right goes to its "owner." Once a system operator has acquired enough rights to protect himself from interference, he registers his satellite system with the IFRB, just as at present.

Jackson's premise is that this approach would defuse much of the growing political opposition that developing nations have to use

of the orbit and spectrum by the developed nations without requiring that economic efficiency be sacrificed. Jackson states that, "the arguments for the necessity and possibility of a spectrum market for international satellites are even stronger than the arguments for the use of market allocation for many domestic spectrum uses. Both equity and efficiency considerations are involved in the allocation of the orbital-frequency resource. A well designed market system should be able to separate these two problems" [22].

Unfortunately, there is reason to question the last statement. Much of what occurs in the international forum is heavily colored by ideology that may not even accept the principles outlined by Jackson and the first part of this paper. Even if orbital slots that could be sold or leased were preallocated to every nation in a manner deemed equitable (a proposal counter to traditional U.S. positions), several political problems would still remain. Some nations, initially finding relatively few buyers for their orbital rights (and all buyers being from developed nations), might see themselves as victims of the monopsony power of the developed nations. Coalitions of nations might decide that the political advantages gained in other areas by using their allotted orbit-spectrum rights for leverage would outweigh the relatively small revenues they might receive from leasing them to users.

Problems of both sorts above have stalled the United Nations Conference on the Law of the Sea for a number of years on the question of deep seabed resource development. One can make a reasonable case

that leasing of deep seabed tracts by an international authority to high technology companies for a limited term of years at a price roughly approximating the economic rent of the activity is an equitable way to proceed with the development of deep seabed resources, especially when the proceeds from the lease are redistributed to lesser developed nations. However, it is only recently, after several years of negotiation, that some of the lesser developed nations have begun to acknowledge that only the economic rent, and not the entire revenue, from these activities should be subject to redistribution. Many nations, seeing that they have little to gain at best from deep seabed resource development, have sought to use the issue for political leverage. There is reason to believe that much of the same kind of thing would make implementation of the Jackson proposal on a worldwide scale difficult, regardless of merit. However, it might be possible, as will be discussed, to employ a regional or even domestic variation of the Jackson plan.

At present, three approaches to allocation of the 11.7 to 12.7 GHz (downlink) band appear to have reasonable probabilities for adoption in ITU Region 2:

1. Rigid Allotment Plan with EIRP's, orbital spacing, frequency assignments specified; slots, channels assigned to nations.
2. Continuation of first-come, first-served principle; fixed and broadcasting satellites sharing the band, broadcasting satellites constrained to orbital arc segments from 75° - 95° W (North America) and 140° - 170° W.

3. Continuation of first-come, first-served principle, separation of services by frequency.

The third approach listed characterizes the expected U.S. position at the 1979 World Administrative Radio Conference. However, there are two ways to divide fixed and broadcast satellite services by frequency, only one of which is acceptable to U.S. interests. For example, the FCC's Tenth Notice of Inquiry (Docket 20271) recommended that the broadcasting satellite service be given a primary allocation in the 12.2 to 12.75 gigahertz band (shared with terrestrial fixed and broadcasting services), and that the fixed satellite service be given a primary allocation in the 11.7 to 12.2 gigahertz band. This arrangement would require either a power-flux-density limit on broadcasting satellites or a detailed frequency coordination plan between broadcasting satellites and terrestrial services, and would cause decreased geographical flexibility. Too stringent power-flux-density limits might preclude the use of earth terminals small enough for low-cost direct satellite-to-home broadcasting.

While some (mostly Region 2 countries interested in satellites primarily for broadcasting) deem this last aspect to be bad, the economist would note that if the value of the additional fixed satellite services that can be offered because of power-flux-density limitations outweighs the additional value of direct broadcasting from satellite to home (as opposed, for example, to broadcast from satellite to community area TV reception stations) then this would be the economically efficient solution. High powered broadcast satellites required

for direct broadcast may require the use of more orbit and spectrum than is justified by the additional aggregate economic value.

Lower powered broadcast satellites broadcasting to community area TV reception stations would generally allow more fixed satellite services to be offered in the same segment of orbit.

Although this latter solution very likely is the one that maximizes the aggregate economic value of the services using the band, most of the benefits from this approach accrue to nations not wishing to use broadcast satellites (mostly developed nations). Even though aggregate economic value is maximized, all parties may not be better off than under alternative schemes. Unless some way is found to redistribute benefits among nations (Jackson's satellite market being one possibility) under the plan proposed by the U.S., stiff opposition can be expected.

An alternative suggested allocation includes both broadcasting and fixed satellites in the 11.7 to 12.75 gigahertz band, with higher powered satellites (i.e., broadcasting) initially assigned to the 11.7 and 12.2 band and lower powered satellites (in the fixed satellite service) initially assigned to the 12.2 to 12.75 gigahertz band. It has been argued that this proposal makes (technically) efficient use of the orbit and spectrum by grouping satellites of similar characteristics and initially constraining higher powered satellites to those frequencies shared with few terrestrial services (making sharing with terrestrial services easier). One objection to this flexible assignment scheme is that accommodations for broadcasting satellites could disappear if faster-growing fixed satellite

services end up requiring the lower part of the band as well.

Allowing the fixed satellite service to use the lower part of the band at all may incur international opposition from other Region 2 countries wishing to use this part of the band only for broadcasting satellites. On the other hand, insistence by these countries that the 11.7 to 12.2 gigahertz band be held idle indefinitely, even in the face of expanding demand for fixed satellite services, might be unacceptable to the U.S., and very likely economically inefficient.

If frequency division of the sort proposed by the U.S. is not adopted at WARC 79 (and this is considered by many to be unlikely), then the U.S. will be faced with the likelihood of an orbit segmentation plan (approach #2 above) or an even less desirable allotment plan (approach #1). One conclusion from the preceding discussion is that, however undesirable the approach ultimately adopted is, the U.S. would be much better off if the orbit-spectrum rights adopted are marketable (transferable) than if they are not. Then, at least, the FCC could go into the world market to buy them or lease them from other nations, if the domestic demand for satellite services warranted their doing so. If the adoption of a rigid plan appears imminent, it might be in the best interest of the U.S. (and other nations with similar concerns) to push for a regional market approach.

Even if such an approach proves to be infeasible throughout Region 2, it might still be feasible for a limited number of nations (i.e., Canada, the U.S., Mexico, Brazil) to collude and pool their allotments in order to achieve the maximum economic value from their

allotments (the market scheme would have to, of course, distribute rents so that each participating party is better off than they would be without such an agreement, but this is one thing the market is well suited for). Mexico, for example, could lease their slots to a foreign party until they were ready to use it themselves (thus, making both better off). Even if no other nations wished to participate in such a scheme, the U.S. could still employ the market approach in domestic distribution of its allotment. Three approaches that could be employed domestically or regionally are described in the following pages:

Policy Option 1 - A Domestic or Regional Market for Orbital Slots

Orbit-spectrum slots are auctioned to the highest bidder. These assignments may then be bought and sold between services if no affected parties are bypassed. The rights auctioned could be defined in a manner similar to the Time-Area-Spectrum right proposed by DeVany et al., but would have both earth to space and space to earth components. On the space to earth component, both in band and out of band maximum permissible power-flux-densities could be stated for areas outside the designated geographical area of coverage (with the out of band limit applying within this area as well). The earth to space component would have analogous limits (not necessarily the same) on in band power levels outside the designated portion of the geostationary arc and out of band power levels generally.

Rights bought by the highest bidder would be perpetual, but transferable. As long as nobody else's rights are affected, parties

could even agree to alter power-flux-density limits as well as the amount of the earth's surface and geostationary arc designated by the right [23]. Furthermore, the relatively small number of systems would make enforcement of these rights fairly easy. Thus, the fixed satellite services, which would presumably be the initial rights holder, could at a later date, within the limits of their ability to share their assignment with a broadcasting party, sell all or part of their rights to a broadcasting party for a sum of money. The broadcasting party would presumably buy up additional orbit-spectrum rights from fixed service parties as long as their marginal revenue product from use of the resource exceeded that for the fixed satellite service.

Policy Option 2 - Administered Total Services Discounted
Cost Minimization

The idea in this proposal is that both satellite services-share frequency allocations and any time a new system, whether broadcasting or fixed, is proposed, the FCC (or the relevant multinational regulatory authority) must include this additional system in the available orbit-spectrum at the lowest aggregate cost over all users. This approach might require the new system to employ more expensive (spectrum conserving) technology than had been anticipated. It could also require previous systems using equipment requiring much orbit-spectrum to change equipment. Which systems must change equipment depends on what combination of changes admits the new system at the lowest aggregate cost.

This policy option is essentially the approach proposed by Lusignan and Russell, in which the party that saves the most gigahertz-degrees

per dollar expended is the party required to conserve spectrum. It differs from coordination (the current procedure for transfer of orbit-spectrum rights) in the respect that no transfer payments between parties need take place for the efficiency of use to be improved. Thus, earlier users need not receive scarcity rents at the expense of later users, as is now the case. Unfortunately, in order for the Lusignan-Russell scheme to work, regulatory authorities must have all the information about technological options and costs available for each satellite system. It is questionable whether this is even remotely possible, and it is the author's opinion that the information problems associated with administrative remedies in general probably make the Lusignan-Russell proposal less attractive than the other more market-oriented policy options presented in this paper.

Policy Option 3 - Leased Rights Distributed by Auction

This proposal is similar to Option 1, except that rights are leased by the central authority rather than sold outright. In fact, the two could be mixed in a hybrid "bonus bid/royalty" scheme if this were deemed desirable.

The lease rate would be a floating rate adjusting continuously to the market value of assignments in the relevant part of the spectrum. This, unlike the outright market sale, would ensure that the governing authority accrues all "windfalls" (which, however, could be negative should the market price decline).

One argument favoring this approach over the outright market sale is that bureaucratic organizations would be much more prone to

reexamine their resource needs if they leased rather than bought spectrum. On the other hand, leasing at a floating rate would burden the user with uncertainty over future prices that would not be faced in an outright sale. Businesses will generally pay a premium to reduce uncertainty about the environment in which they expect to be operating, especially when they are contemplating longer-term investments. Furthermore, prices would have to increase dramatically for a true windfall to occur in an outright sale of spectrum assignments. Nevertheless, this option offers an alternative for those who feel that any kind of windfall accruing to a private party under any conditions is unacceptable.

In fact, the choice of lease or sell could conceivably be based on the particular nature of the parties involved. Alternatively, leasing together with encouragement of options or futures contracts could be employed. Under either system, coalitions of parties offering different services that could share an assignment would be capable of offering higher bids than a single service that excluded the use of all other services from that part of the orbit spectrum. Both would tend to lead to more efficient use of the resource.

Several observations can be made about the three policy options described above. First, economic efficiency need not be coupled to distributional equity. In fact, because economically efficient use maximizes the aggregate economic value derived, it is possible that nations participating in an economically efficient allocation scheme could all be better off than they would be under an inefficient

alternative (such as nontransferable nation by nation assignment of channels and orbital slots). This last observation suggests the possibility of multilateral collusion to adopt market or quasi-market techniques in ITU Region 2 for assignment of orbit-spectrum. Such a scheme could even be embedded by agreeing nations within the rigid plan being advocated by some nations, provided transferability of allotted orbital slots or frequencies is maintained. Such an approach should be examined as a possible fallback, should U.S. positions at WARC 79, or at the proposed 1983 Region 2 conference be rejected.

A more important observation is that all three schemes give the designers/operators of satellite systems the incentives to make correct trade-offs between technology and orbit-spectrum resource use—incentives that are either absent or distorted in the present (zero-price rationing) administrative approach. Instilling the correct incentives will be especially important if the number of satellite orbital slots available to the U.S. is severely limited by international orbit-wide planning. In fact, it is possible that the same mechanisms that instill these incentives (payment of scarcity rent by users) could play a role in reducing the attractiveness of such worldwide planning even to those nations most enamoured with it. Once the appearance of users getting something for nothing is eliminated, the international political interest in orbit-spectrum assignment might disappear.

III. EPILOGUE

Orbit-Spectrum is the only commercially useful space resource developed by mankind so far, but, hopefully, not the last. For those who believe other space resources will indeed be developed, orbit-spectrum serves as a useful prototype highlighting some of the problems development of other space resources can expect to encounter.

Fifty years ago, orbit-spectrum was a worthless resource. Today, this is far from being the case, as the continuing political conflict between nations over its allocation so vividly illustrates. Many of the lesser-developed nations have demanded that they be apportioned their fair share of the resource, even though they have no real intention of using it themselves. But, what made this once worthless resource so valuable?

The answer to this last question is, of course, technology--specifically, technology developed by a handful of industrialized nations. One might argue that, since orbit-spectrum is a nondepletable resource made useful only by the investment of these nations, it is only fair that they use it as they see fit. According to this view, leasing of orbital slots through an international authority would lead to accrual of economic rents by lesser developed countries (LDC's) not truly earned--thus, a leasing arrangement would be really quite generous to the LDC's.

Unfortunately, the LDC's don't see it this way. Some believe, rightly or wrongly, that the wealth of the industrialized nations was

accumulated by exploitation of what are now lesser developed nations during the colonial period. They view orbit-spectrum as one of many "common heritage" resources (i.e., not by their location naturally belonging to any one nation) that should be evenly distributed among the nations of the earth, but are likely to be appropriated by the (first-come) industrial nations. That the resource is now rationed free of charge strongly reinforces the plausibility of the view that a "common heritage" resource is being unjustly appropriated by the industrialized nations.

An international leasing market would result in income redistribution that might defuse the militance characterizing some LDC's recently but not destroy the incentives of the industrialized nations to continue technological development improving resource utilization.

It would be naive to believe, given what has transpired in the case of the first renewable space resource, that the U.S. would not receive a great deal of political heat for exploiting nonrenewable space resources, such as space minerals. Any future "space policy" must be prepared to address this problem on at least the rhetorical level, though it's not so far-fetched to imagine world politics leading to the creation of an international authority to lease space mineral rights [26].

The other question of interest only briefly discussed in the body of the paper concerns how the channeling of research and development funds is affected by the assessment of a resource's value. Because there are not market prices for "orbit-spectrum," there is

a tendency to improperly compare different parts of the same resource. For example, the 30/20 gigahertz band is not as easily usable (hence valuable) as the 6/4 band. Yet, the two are described as almost perfect substitutes in R&D discussions. Proper valuation would give a better measure of the return on both extensive and intensive development, and thereby a better idea of where to spend public R&D moneys.

Notes

1. Rather arbitrarily defined as frequencies between 0 and 300 gigahertz (GHz). 1 gigahertz = 1 billion cycles per second.
2. The word "allocation" has two meanings in this paper. The usual meaning refers to the distribution of economic resources in general. The specific meaning refers to the process by which classes of services are allotted a region within the spectrum. It is hoped that which meaning is intended will be clear from the context.
3. Section 301 of the Communications Act of 1934 contains essentially the same language.
4. Ronald Coase argues that the Congress overreacted by passing the Radio Act of 1927, adopting a solution far more encompassing than avoidance of destructive interference required. He argues that the courts would have, in time, arrived at a workable definition of radiation rights optimizing the level of destructive interference even with no legislation at all. Coase, Ronald H., "The Federal Communications Commission," Journal of Law and Economics, II (Oct., 1959). Charles Jackson counters that the importance of interference-free radio communications to the safety of maritime operations (the primary user of radio spectrum in the early part of the century) and the then relative simplicity of an administrative solution (prior to an era when billions of dollars could hinge on the outcome of a decision, or for that matter, when spectrum was even noticeably scarce) makes the "press for government monopoly more understandable." Jackson, Charles L., "Technology for Spectrum Markets," PH.D. Dissertation, MIT, 1976.
5. Descriptions of the allocation and assignment process appear in Coase, op. cit., and Robinson, John O., "An Investigation of Economic Factors in F.C.C. Spectrum Management," F.C.C. Report No. SAS 76-01.
6. A discussion of this information overload problem appears in Robinson, Glen O., "F.C.C.: An Essay on Regulatory Watchdogs," Virginia Law Review, Vol. 64, 1978.
7. There are, of course, a number of nontrivial assumptions being made here about what constitutes "highest value" in a social sense. However, even when social value is somehow determined to differ from market price, there are still ways to employ market mechanisms, and their attendant information economies, to the distribution of resources. For a discussion of this problem see Schultz, Charles, The Public Use of Private Interest, Brookings Institution, Aug., 1977.

8. In fact, many view price systems as nothing more than a highly efficient information system serving to promote mutually beneficial transactions between parties.
9. Owen, Bruce M. "Spectrum Allocation: A Survey of Alternative Methodologies," Office of Telecommunications Policy Staff Paper, April, 1972.
10. Coase, in a footnote on page 27 of his article (op. cit. note 4), remarks that his most fundamental complaint is that certain desirable market transactions are impossible under current law.
11. Henderson and Quandt, Microeconomic Theory, 2nd ed., p. 279, McGraw Hill, 1971.
12. Robinson, John O. "Introduction to Economic Factors into Spectrum Management," Masters Thesis, p. 28, Annenberg School of Communications, Univ. of Pennsylvania, 1974.
13. Note that opportunity cost minimization is not the same as accounting cost minimization. The latter is minimized by zero output whereas the former is not--idle resources have a positive opportunity cost.
14. Not that I am the first to address them--indeed, many have. However, no matter how many times they are addressed they crop up again and again.
15. As used here, "enforcement" includes both detection of a violation of somebody's rights, and adjudication for purposes of resolving disputes over rights or punishing offenders.
16. This crude model is designed only to illustrate a point. Note that it is not capable of handling the more likely situation where A's violation of B's right is unintentional. The simple model could be extended by allowing A either to expend an amount e to be assured he is violating nobody's rights, or expend nothing and face probability q that he is violating somebody's rights. Letting b^* be the state of the world in which A has expended e to be sure that no violations have occurred, the decision criterion becomes:

$$U(b^*) > (1-q)U(b) + q[(1-p)U(a) + pU(c)]$$

If e depends on q in an appropriate way (i.e., $q > 0$ then $e > 0$ and $b^* > b$) and $U(a) > U(b) > U(c)$, then there will always be a p between 0 and 1 such that for all probabilities greater than this p , A will expend e to guarantee that he is violating nobody's rights. If feelings of guilt accompany a violation

16. (continued)

of somebody else's rights then it may be that $U(b) > U(a)$. If this were true for everybody in society, then, according to the simple model, no violations would occur, even if society spent nothing on detection ($p=0$). Thus, the social purpose of guilt may be largely that of keeping enforcement costs down.

As for the trade-off between detection probability and punishment, Gary Becker has noted that "a common generalization by persons with judicial experience is that a change in the probability has a greater effect on the number of offenses than a change in the punishment. . .," Becker, Gary S. "Crime and Punishment: An Economic Approach," Journal of Political Economy, pp. 169-217, March-April, 1968.

17. DeVany, Arthur S., Eckert, Ross D., Meyers, Charles J., O'Hara, Donald J., & Scott, Richard C. "A Property System for Market Allocation of the Electromagnetic-Spectrum: A Legal-Economic-Engineering Study," Stanford Law Review, XXI, pp. 1499-1561, June, 1969.
18. Dunn, Donald A., & Owen, Bruce M. "Policy Options in Mobile Radio Spectrum Management, Report to the F.C.C., Sept., 1978.
19. Reinhart, Edward E. "Orbit-Spectrum Sharing Between the Fixed-Satellite and Broadcasting-Satellite Services with Applications to 12 GHz Domestic Systems," NASA Report R-1463, p. 189, May, 1974.
20. For example, Reinhart's report, previously noted.
21. Jackson, Charles L. "Technology for Spectrum Markets," Ph.D. Thesis, p. 71 ff., MIT, 1976.
22. Ibid 21.
23. How negotiations of this kind might be effected is extensively described in the article by DeVany, Eckert, Meyers, O'Hara, and Scott, referred to in note 17.
24. Russell, S. P., & Lusignan, B. B. "A Techno-Economic Approach to U.S. Domestic Satellite Orbit-Spectrum Regulation," IEEE Compatibility, Vol. EMC-19, No. 3, p. 351, Aug., 1977.
25. This approach is discussed in detail by Jackson in "Technology for Spectrum Markets," op. cit. note 21.

26. For those to whom this seems too "far out," I would only point out that the same could have been said 100 years ago about the idea that apportionment of deep seabed resources would someday become the politically heated issue it has in fact become in recent deliberations at the Third U.N. Conference on the Law of the Sea.